How to Select the Correct Power Sensor
Primer

One of the most fundamental RF measurement tools is the power sensor. Today, the marketplace is filled with lots of choices and bold claims of fast speeds and large numbers of readings per second, but when sifting through the datasheets it can be difficult to determine what sensor will meet the needs for any particular measurement. In this white paper we will review the fundamentals of RF power sensors and discuss what you need to consider when selecting a power sensor.

Primer
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ROHDE&SCHWARZ

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Today, the RF power sensor marketplace is filled with bold claims of fast speeds and large numbers of readings per second, but when sifting through the data sheets, it can be difficult to determine what sensor will meet the needs for any particular measurement. In this white paper we will review the fundamentals of RF power sensors and discuss what you need to consider when selecting a power sensor.

The paper is split into three sections. First, how to choose the right type of sensor - from multipath and wideband to thermoelectric sensors, all fulfilling slightly different measurement needs. Next we'll cover sensor performance, how it's defined and what to look for. Finally, we'll discuss ways to integrate a sensor into your measurement application.

1 How to Choose the Right Type of Sensor

The type of signals and the required measurements greatly influence the sensor choice. Knowing this information is the first step in determining what type of sensor you will need.

First, what signals do you need to measure?

- Is it a CW signal?
- Does the signal have any analog or digital modulation?
- Are you trying to characterize a pulsed signal?

Next, what measurements do you need to make? Examples include:

- Average power (CW and/or modulated signals)
- Time slotted measurements
- Envelope power versus time
- Statistical analysis such as CCDF, CDF and PDF

There are four categories of sensors: multipath, wideband, average and thermoelectric. The next sections describe each of these sensors and their capabilities for the different types of signals and measurements.

1.1 Multipath Sensors

Multipath sensors, also sometimes called the universal sensor, are by far the most popular type. They get their name from the fact that they have separate diode paths for different power ranges. For example the Rohde & Schwarz multipath sensors employ an architecture with three paths, see Figure 1-1.

Each of the different measurement paths measure the incoming signal simultaneously and each path is optimized for a specific power range designed so that the ranges overlap each other. Unique algorithms and weighting processes are used on each path to determine the measured result. The results from each of the paths are summed together to deliver accurate results.

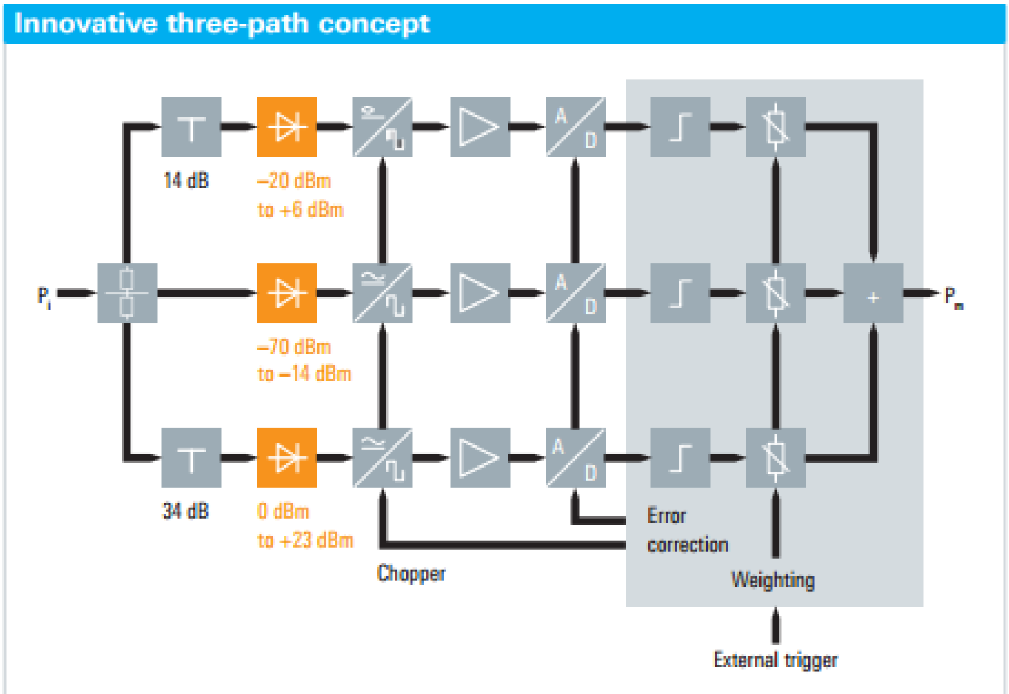

Figure 1-1: Multipath sensors offer the widest measurement range and fastest speeds by utilizing separate diode paths for different power ranges.

Multipath sensors can perform a wide range of measurements, including continuous average measurements, burst average, time slot measurements, gated measurements, and trace measurements. Figure 1-2 shows some of the ways you could configure a multipath sensor to make time slotted measurements.

The primary advantage of multipath sensors is that they offer the widest measurement range, the fastest measurement speed and good accuracy, generally making them the best all-around type of sensor that will fit a majority of applications. The one disadvantage of a multipath sensor is its video bandwidth, which can be too narrow for some pulse measurements.

The key takeaway when looking at multipath sensors is to make sure that the paths are overlapping and measuring simultaneously. This will ensure both fast and accurate results.

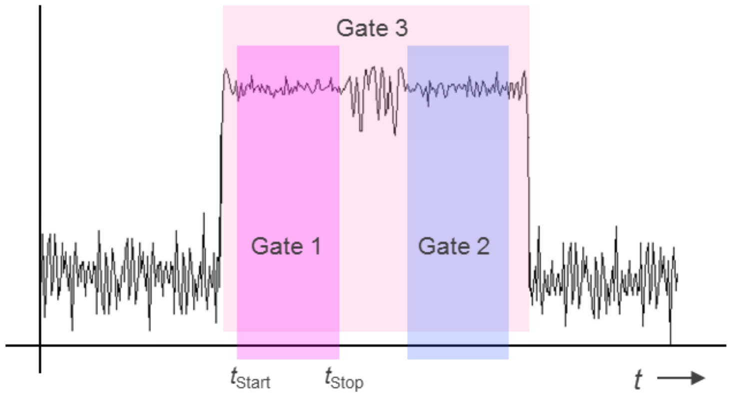

Figure 1-2: Multipath sensors may be configured for a wide range of measurements.

1.2 Wideband Sensors

Wideband sensors offer a wider video bandwidth and are therefore better suited for dealing with fast pulses or wideband signals. This also allows them to offer more measurement types, such as envelope statistics, pulse analysis, and time analysis.

Wideband sensors are ideal for analyzing envelope power and doing wideband time based analysis on fast rising pulses. The diagrams in Figure 1-3 show a few of the different types of measurements you could make with a wideband sensor. The disadvantage of a wideband sensor versus the multipath sensor is slightly less measurement range and a slightly higher measurement uncertainty.

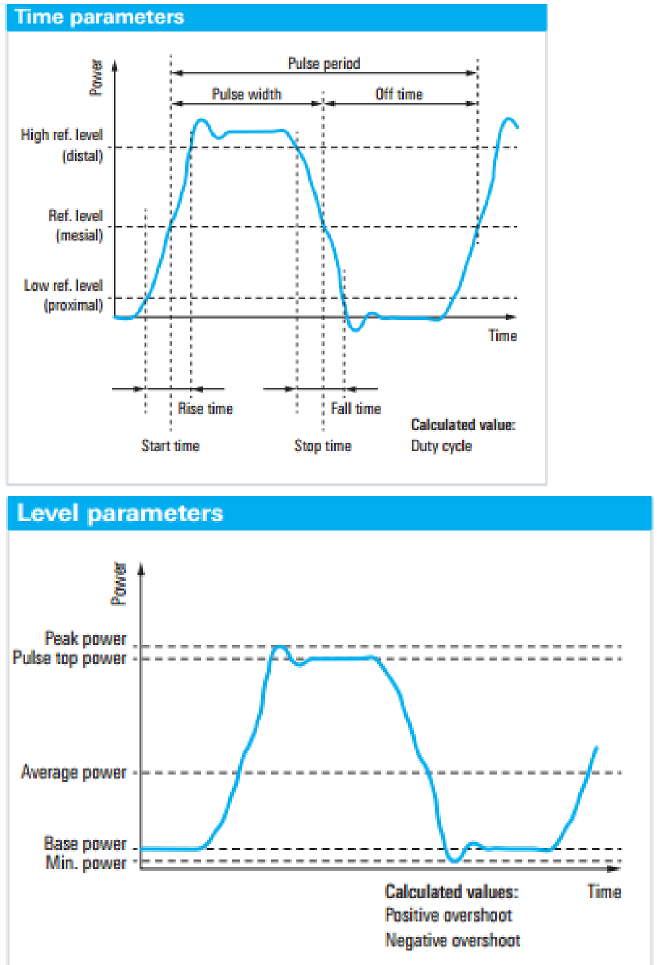

Figure 1-3: Wideband sensors offer more measurement types, such as envelope statistics, pulse analysis, and time analysis.

1.3 Average Power Sensors

An average power sensor is basically a scaled down version of a multipath sensor. Its measurement capabilities are limited to average power for both CW and modulated signals.

Average power sensors are used for example in EMC applications, where usually only the average power is of interest. Average power sensors cover measurement ranges that are used in radio telecommunications (up to 6 GHz) as well as the important lower frequency bands (down to 9 kHz). Users benefit from the excellent properties of the three-path diode power sensors. The disadvantage is, they do have limited measurement functionality, as they only allow average measurements to be made.

1.4 Thermoelectric Sensors

Thermoelectric power sensors are the most accurate types of sensors. To improve measurement accuracy, the hardware is designed to reduce measurement noise to a minimum and to make the sensor immune to thermal environmental effects. They also have the highest frequency coverage – all the way from DC to 110 GHz, however they are limited to average power measurements, which limits their overall measurement capability. Thermoelectric power sensors are often used for complex measurement tasks. An ideal application would be a calibration lab or similar demanding applications that require high performance reference measurements.

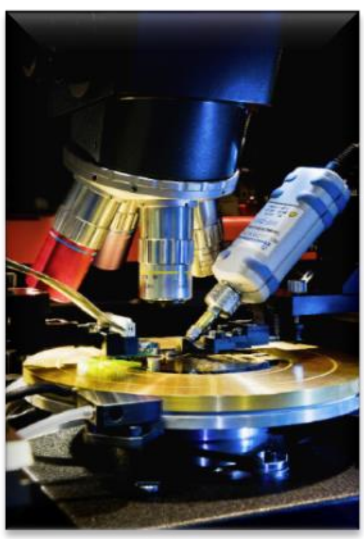

Figure 1-4: Thermoelectric power sensors are especially used in calibration labs and demanding applications that require high performance reference measurements.

1.5 Power Sensor Review

Table 1-1 summarizes the different types of measurements that can be made with the different types of sensors. Knowing what measurements you need to do is key to understanding what type of sensor you will need.

	Multipath	Wideband	Average	Thermoelectric
Average Power (CW)	Y	Y	Y	Y
Average Power (Modulated Signals)	Y	Y	Y	Y
Average Power (Modulated Signals, Gated)	Y	Y		
Pulse Power	Y	Y		
Envelope Power	Y	Y		
Envelope Statistics		Y		
Pulse Analysis		Y		
Time Analysis		Y		

Table 1-1: Power Measurements by Sensor Type

2 How Is Sensor Performance Defined?

Next we will discuss sensor specifications, which will help you evaluate the different products in the market and choose the one that's right for your application.

Sensor performance is defined on four levels:

- Frequency range
- Measurement level range
- Measurement uncertainty
- Speed

It's important to note that many of these also interact with each other, having an additional impact on the overall power sensor performance.

2.1 Frequency Range

Frequency range is a fairly straightforward specification. You need to be sure to choose a sensor which has the frequency range to cover the signals of interest. The one thing to note is that power sensors are not frequency selective. They're not like a spectrum analyzer, which can be narrowed in to just measure the power at any given point or any given frequency. Instead a power sensor will measure the power of all the signals within its operating range.

2.2 Measurement Level Range

The measurement level range, sometimes called dynamic range, is the difference between the maximum and minimum power levels that the sensor can measure. Typically a datasheet will show a range of power specification from, for example, -70 to +23 dBm. It is important to understand to what type of measurements this specification applies. As discussed earlier, sensors may make different types of measurements and each different measurement type will have its own measurement range specification.

Table 2-1 shows the measurement level ranges of an example Rohde & Schwarz sensor. Each one of the different types of measurements has its own measurement range specification. This may become very important if you're measuring low-level signals, because the impact and the limitations of the different measurement ranges is often at the lower end of the power range.

Measurement	NRP8S/N
Continuous Average	-70 dBm to +23 dBm
Burst Average	-35 dBm to +23 dBm
Timeslot/Time Gated Average	-65 dBm to +23 dBm
Trace	-57 dBm to +23 dBm

Table 2-1: Measurement Level Range Specification for R&S®NRP8S Power Sensor

2.3 Measurement Uncertainty

This section will review not only the sensor uncertainty specifications but also external considerations that may impact your overall measurement uncertainty. We'll also show how to calculate and improve the uncertainty.

2.3.1 Sensor Specifications

Power Sensor datasheets typically provide an uncertainty specification. It covers internal factors like calibration uncertainty, linearity, and changes over temperature. The specification is given for a defined frequency range, input power level, and an ambient or room temperature range.

Uncertainty specifications are provided either in dB or as a percentage. Table 2-2 shows the uncertainty specification for the R&S®NRP8S, same power sensor as shown in Table 2-1.

> 2.4 GHz to 8 GHz Power level in dBm	–70 to –20	–20 to 0	0 to +23
0 °C to +50 °C	*0.162*	*0.168*	*0.164*
+15 °C to +35 °C	*0.088*	*0.089*	*0.088*
+20 °C to +25 °C	*0.065*	*0.063*	*0.064*

Table 2-2: Uncertainty Specification for R&S®NRP8S

The equation that relates dBs and percentages is:

$$U_{dB} = 10\ x\ \log_{10}(1 + \frac{U_{\%}}{100})$$

2.3.2 External Considerations

A key thing to note is that the uncertainty specification in the datasheet does not reflect the overall measurement uncertainty. The sensor uncertainty specifications are based on factors that are internal to the sensor. As these are internal, they are predictable and can be measured while the sensor is being manufactured. However there are also other external factors that have an impact on measurement uncertainty.

First, consider the test setup. What is the VSWR of the sensor compared to the VSWR of the device under test (DUT)? The mismatch between these two devices is obviously going to impact how much power enters the sensor. If there is a lot of mismatch between these two devices - the power going into the sensor is going to be a combination of the true power coming out of the device, plus a combination of the reflections from the DUT and sensor. This mismatch is going to change how much power enters the measurement port of the sensor, which in turn will effect measurement uncertainty.

Secondly, there are other power sensor characteristics which are set not by the sensor itself, but by the way the sensor is being used. These include: zero offset, zero drift, and measurement noise. The datasheet includes specifications for these, but the values that you use and how they impact the measurement uncertainty depend on the actual setup. For example, measurement noise may have an impact on your results, especially when you're measuring low-level signals.

Finally, the sensor measurement settings, such as averaging and aperture time need to be considered. Averaging increases the number of times that the power from the DUT is read before the result is shown. Aperture time is how long we're looking at the signal each time we make a reading. The more averages taken and the longer the aperture time, the more accurate the results will get. Since the user sets the number of averages and aperture time, it's not included in the uncertainty specification given in the datasheet.

2.3.3 Calculating Total Measurement Uncertainty

Combining all these factors gives an ability to determine the overall measurement uncertainty of your test set up. Any power sensor datasheet provides equations that put them all together to determine an overall uncertainty value.

Rohde & Schwarz also provides a Windows-based software calculator (Figure 2-1). The calculator provides a nice user interface to enter the specific values and allows you to quickly determine your overall measurement uncertainty. The results are shown in both percentage and in dB, plus it also shows the measurement time. The calculator allows you to play around with the variables to see what impact they have on your measurement uncertainty and find the optimum setting for your power sensor. Additionally, the software is preloaded with all the specification data for the Rohde & Schwarz power sensors.

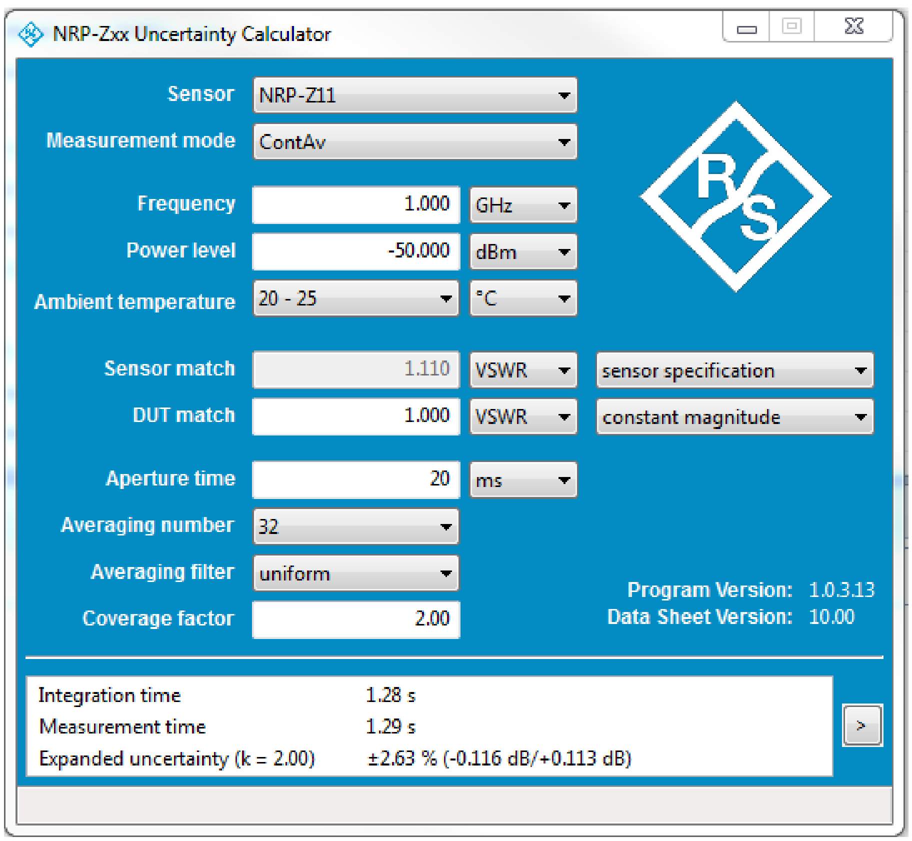

Figure 2-1: Rohde & Schwarz offers a software calculator that helps you quickly determine your overall measurement uncertainty.

2.3.4 Improving Measurement Uncertainty

VSWR is the part of your test set up that can be compensated for and it can have the biggest impact on measurement uncertainty. This includes both the VSWR of the sensor and of the DUT. Sensors are able to compensate for the effect of VSWR mismatch using a feature called “Gamma Corrections.” By knowing the DUT and sensor reflection coefficients it enables the sensor to minimize the impact of mismatch on the overall measurement uncertainty.

An example is shown in Figure 2-2. The top chart shows mismatch contribution to be nearly 0.3 dB before Gamma Corrections. If you know the VSWR of the sensor and of the DUT, they can be loaded into the software and corrected using the Gamma Correction feature. The bottom chart, with the gamma corrections switched on, reduces the mismatch nearly to zero. Once the gamma corrections are utilized, the total measurement uncertainty drops from nearly 0.3 dBs to 0.1 dB, which is a significant change.

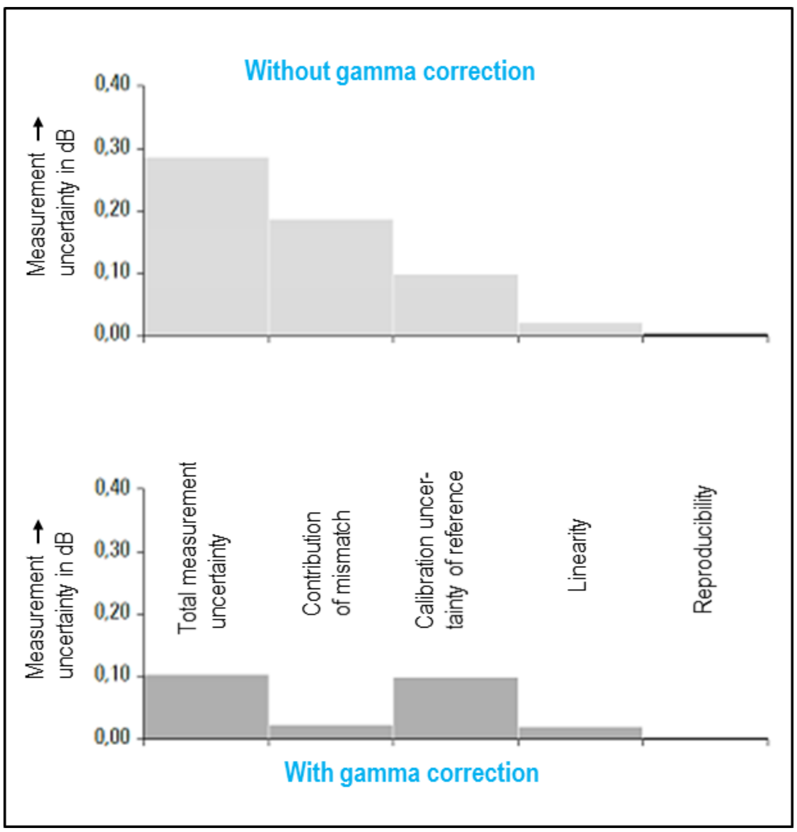

Figure 2-2: Gamma Corrections may be used to limit the impact of mismatch on the overall test setup uncertainty.

Measurement accuracy is also effected by any components between the sensor and DUT, including cables, attenuators, splitters, etc. These components will add losses and reflections into the measurement path.

If you know the S-parameters of these accessories, or measure them on a network analyzer, the information can be entered into the power sensor and corrected (Figure 2-3). Adjusting for the S-Parameters of these components and reducing the impact these have, accurately shifts the measurement plane from the input of the sensor to the output of the DUT thereby providing another way of improving accuracy.

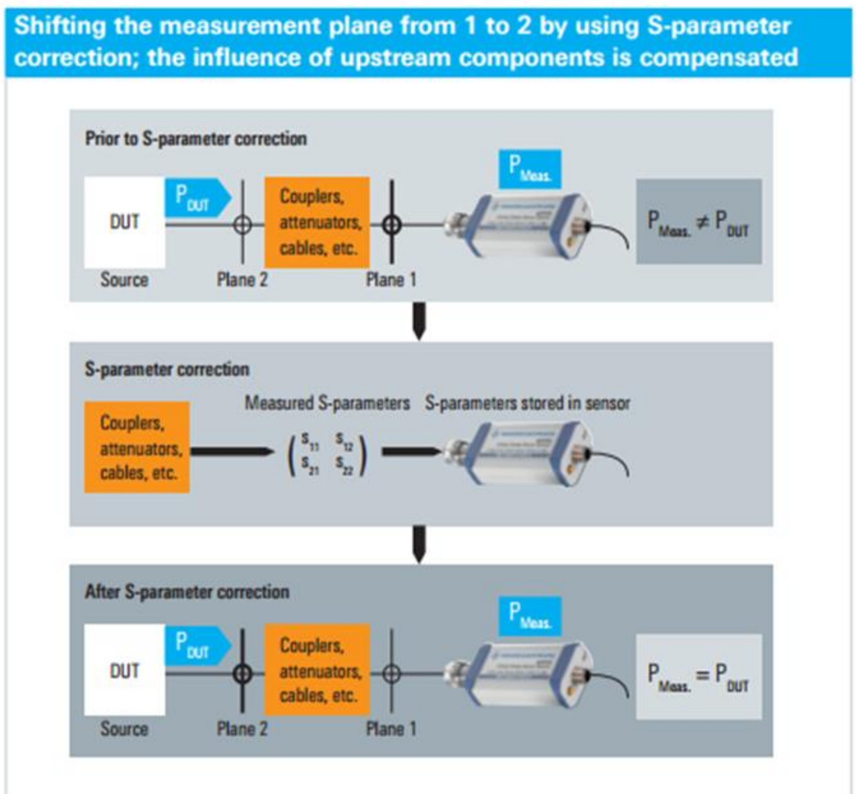

Figure 2-3: Use S-parameters to compensate for external components and improve uncertainty.

2.4 Measurement Speed

It is very common for power sensor manufacturers to advertise fast speeds and large amounts of data collection per second. Performance can be specified as "readings per seconds." However, this is different from "measurements per second." A reading is the time it takes to make a single power reading from the DUT. A measurement is made from enough readings that can be averaged to give you the desired accuracy. The key is that the time to deliver accurate results depends on much more than just the "speed" specification.

Let's look at a measurement example to understand the interaction between speed and accuracy (Figure 2-4). In this example we need to measure a signal that's -60 dBm, with an accuracy of ±0.1 dB. For this measurement we use two sensors and let's assume that they have the same measurement speed and the same uncertainty specifications.

Sensor #1 has a noise floor of -67 dBm. The y-axis shows the power level and the white bar in-between the blue boxes is the ±0.1 dB tolerance level. If we make one measurement with one average, as shown in the grey line, the reading bounces around. Setting the number of averages to four starts to settle out the result, but still not within the ±0.1 dB tolerance level. Not until the number of averages is increased to 64, the red line, does the result show that we meet the desired tolerance level.

Sensor #2 has a noise floor of -70 dBm. Now let's measure the same signal and step through the same set of averages. From the data we can see that with 16 averages (green line) we can determine that the DUT meets the desired tolerance level.

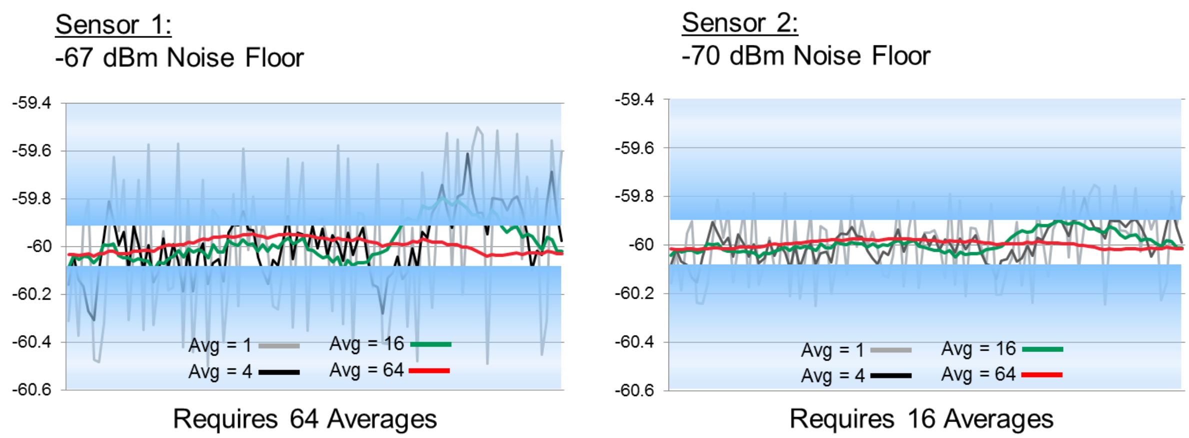

Figure 2-4: In this example, two sensors with similar speeds and uncertainty, but one having a lower noise floor, gets the same results four times faster.

So the two sensors with similar speeds and uncertainty, have a dramatic difference in overall measurement time. The 3dB lower noise floor of Sensor #2 allows it to be used with 16 averages versus the 64 averages required by Sensor #1. In this case, by choosing a sensor with a lower noise floor you will get the same results four times faster. So in this case it may not matter how fast the sensor is working, because if you are able to make less averages, you will get your results faster.

2.5 Sensor Performance Review

The previous example showed a definite relationship between speed and accuracy. When choosing a power sensor that will give accurate results quickly, you need to look at three things.

First, you need to choose an accurate sensor with a lowest measurement uncertainty. Second, you should choose one with a low noise floor for all the different measurement types. Finally, you should choose one that can make readings quickly (the speed specification).

The key takeaway is to evaluate all the performance characteristics of a sensor and keeping in mind that they are each related. Accuracy, speed, and noise floor all affect how quickly you get accurate results from your sensor. Remember that for every 3 dB reduction in your noise floor, there is 50 percent less noise, which is significant when measuring low-level signals.

3 Different Ways to Integrate a Sensor

Next let's consider the different ways that a power sensor can be operated. The type of sensor you need, may depend on how you want to integrate the sensor into your application.

3.1 USB Interface Control

Most sensors today are USB-based. Rohde & Schwarz actually introduced the first USB sensor over ten years ago. With a USB sensor all of the measurements are made in the sensor head itself, meaning it can be operated without the use of a traditional power meter. These sensors can be controlled manually from dedicated software on a PC, or can be controlled remotely in automated test environment (ATE).

For field use, Rohde & Schwarz also has an application available for Android devices. This will allow you to make power measurement capabilities and tests, using your handheld device – either tablet or phone.

Figure 3-1: USB based power sensors are the most popular today due to their flexible control interface and portability.

3.2 Direct Ethernet Control

Today, many sensors can be controlled over Ethernet via an integrated LAN port, delivering the same measurement performance and capabilities as the USB sensor. The added ability is access to the sensor through a network, either a corporate network or the public Internet (Figure 3-2). These are ideal for ATE systems, where much of the test equipment programming maybe through Ethernet. And, like the USB sensor, using Ethernet to control the sensor removes the need for a power sensor.

Ethernet control is also very useful when working with remote monitoring sites. It could be a transmission tower out in the field or on top of a building with a power sensor installed and connected to the Ethernet. No need to go to the site to make the measurements, you can just log on from any one of your devices – laptop, mobile phone or tablet, and make measurements in real-time. Many of the leading LAN sensors have a built-in Web server, which greatly simplifies how manual measurements can be made on these types of sensor.

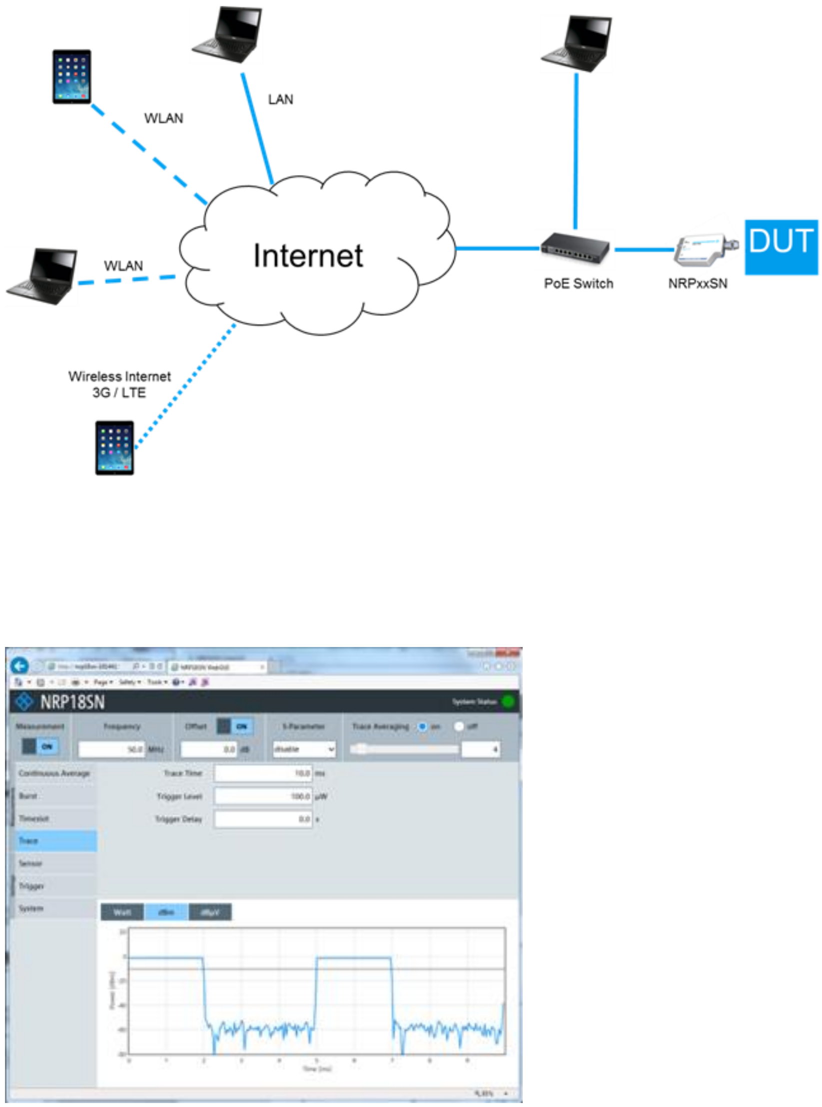

Figure 3-2: LAN sensors are ideal for ATE systems or remote monitoring site and offer a built in web server that allows for real-time monitoring from multiple locations.

3.3 Traditional Base Unit

The traditional base unit can be manually controlled and displays the results on its front panel. The base unit doesn't actually make the measurements, it is just for display and control. One of the benefits of using a base unit is that it can control multiple sensors from a single instrument. That allows for a single trigger into the base unit to simultaneously trigger up to four sensors.

For remote control environments, the base units can be controlled over either GPIB, LAN, or USB. It also has a built-in reference source which can be used to check the operation and performance of the power sensor, without the need of a separate signal generator.

Many of the base units also have an emulation mode which allows them to be drop-in replacements for older legacy power meters. There are many previous generations of traditional base unit power meters which are still operational but maybe no longer supported. If these older units are controlled by software, replacing them usually means the software needs to be changed, which is costly and time consuming. The emulation mode can save both time and money because it enables the new base unit to understand the commands meant for the older unit. Not having to update old software code can be a big advantage. Plus the new base unit allows newer power sensors to be used and this may deliver more accurate results and potentially improve throughput.

NRP2 Base Unit Emulates the following:
- R&S NRVD
- HP436A, 437B, 438A
- Agilent N1911A, N1912A, E4418B
- E4419B, N432A

Figure 3-3: Traditional base units can manually control and make measurements from the front panel. Using the R&S®LegacyPro Emulation Mode enables drop in replacement of legacy power meters.

4 Summary

In this white paper we learned that the type of sensor you need can be determined by first defining your signal types and measurement requirements. Understand your signal and measurement requirements, and you will know the type of sensor to choose.

The next step is to compare performance and specifications of the different sensors. This compare should be much more than just looking at the banner specifications. Understanding how the different measurement ranges, the measurement uncertainty performance and the speed all related to each other, will lead you to choose the correct sensor that can deliver accurate measurement results quickly. Use tools like the Rohde & Schwarz calculator software to determine if the performance will meet your needs.

Rohde & Schwarz has a portfolio of power sensors and base units, with leading performance, lowest noise floor, lowest measurement uncertainty factors, and fastest measurement speed. And, this performance is combined with outstanding usability capabilities, like a LAN interface, built-in triggering, gamma corrections, and compensation for S parameters.

For more information on Rohde & Schwarz power sensor product information, application notes, selection guides, and the uncertainty calculator, visit:

http://www.rohde-schwarz.us/en/products/test-measurement/power-meters-voltmeters/products/overview_63672.html

To download the R&S®NRP toolkit, visit:

http://www.rohde-schwarz.us/en/software/nrp2

Rohde & Schwarz

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